Normalizing to the Number of Stopped Muons in the Mu2e Experiment

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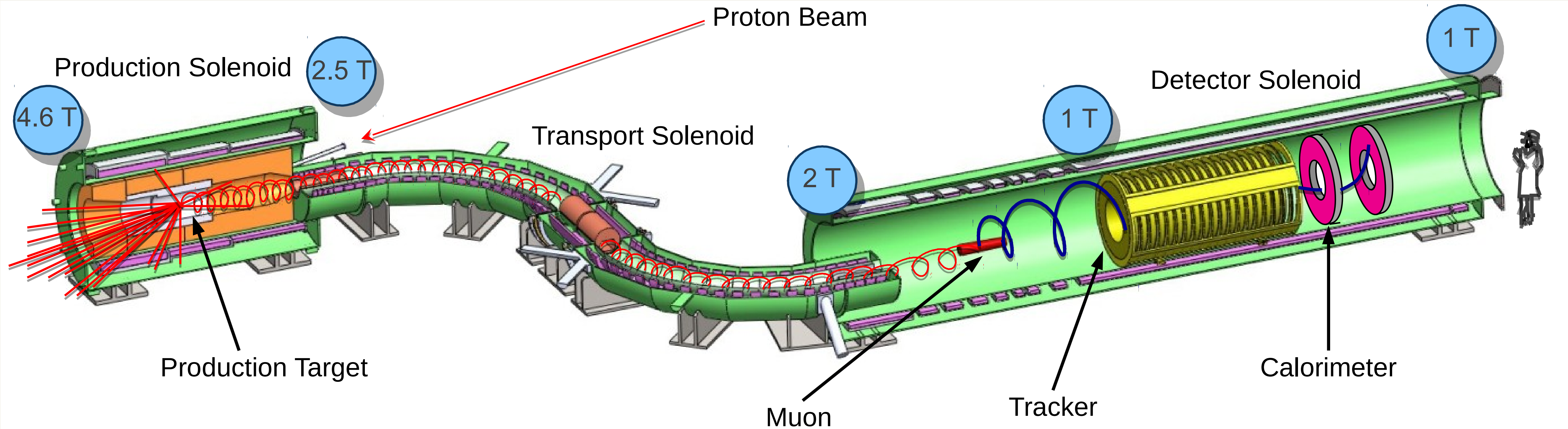
for the Mu2e Collaboration

Outline

- Overview
- Conceptual design
- Simulation results
- Outlook

Overview

- Mu2e is going to probe μ-e conversion in an muonic atom at an unprecedented sensitivity



$$\mu^- + {}^{27}_{13}\mathrm{Al} \to e^- + {}^{27}_{13}\mathrm{Al}$$

The number of stopped muons

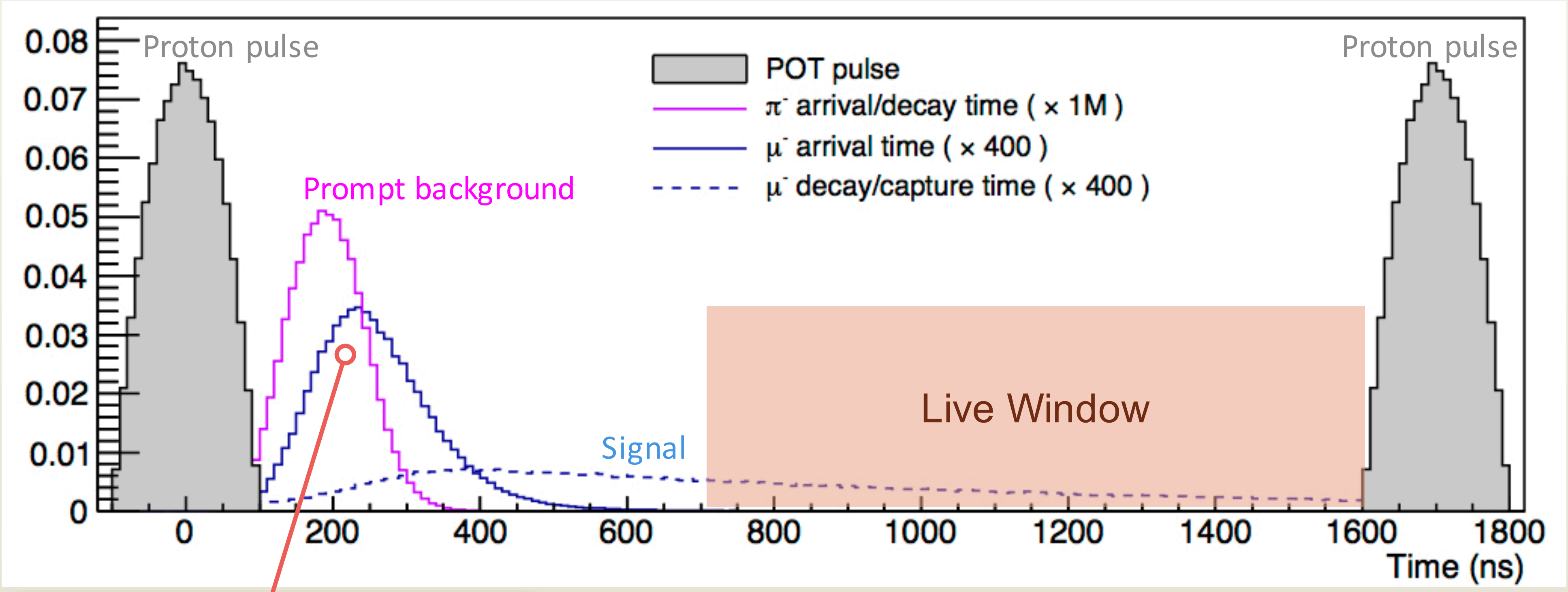
- Mu2e is going to probe μ-e conversion in an muonic atom at an unprecedented sensitivity

$$\mathrm{S.E.S.}(\mu^- + \mathrm{Al} \to e^- + \mathrm{Al}) = 3.0 \times 10^{-17} \sim \frac{1}{N_\mu}$$

- Number of stopped muons N_μ
  - designed value $N_\mu = 6.8 \times 10^{17}$
  - need to measure in the real experiment to 10% precision

Pulsed proton beam

- 6×10^{20} protons delivered in 3 years
- Proton pulses are 1695 ns apart
  - 3.1×10^{7} protons per pulse
- Conversion electron search window: 700 - 1600 ns

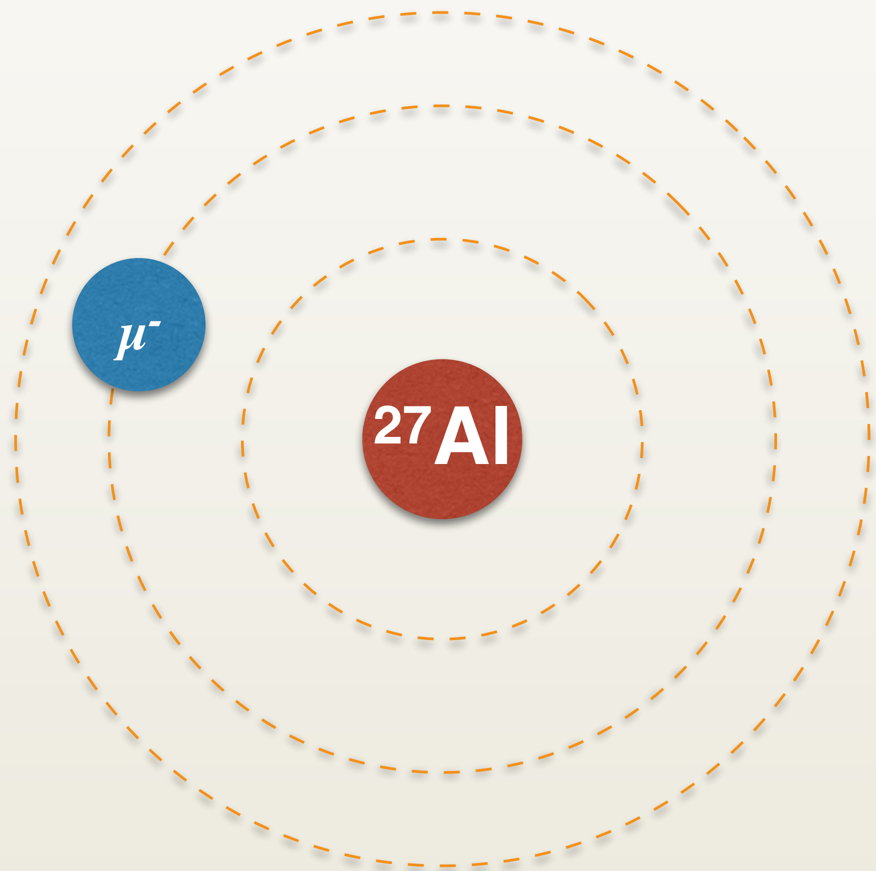


π, μ arrives at the muon stopping target

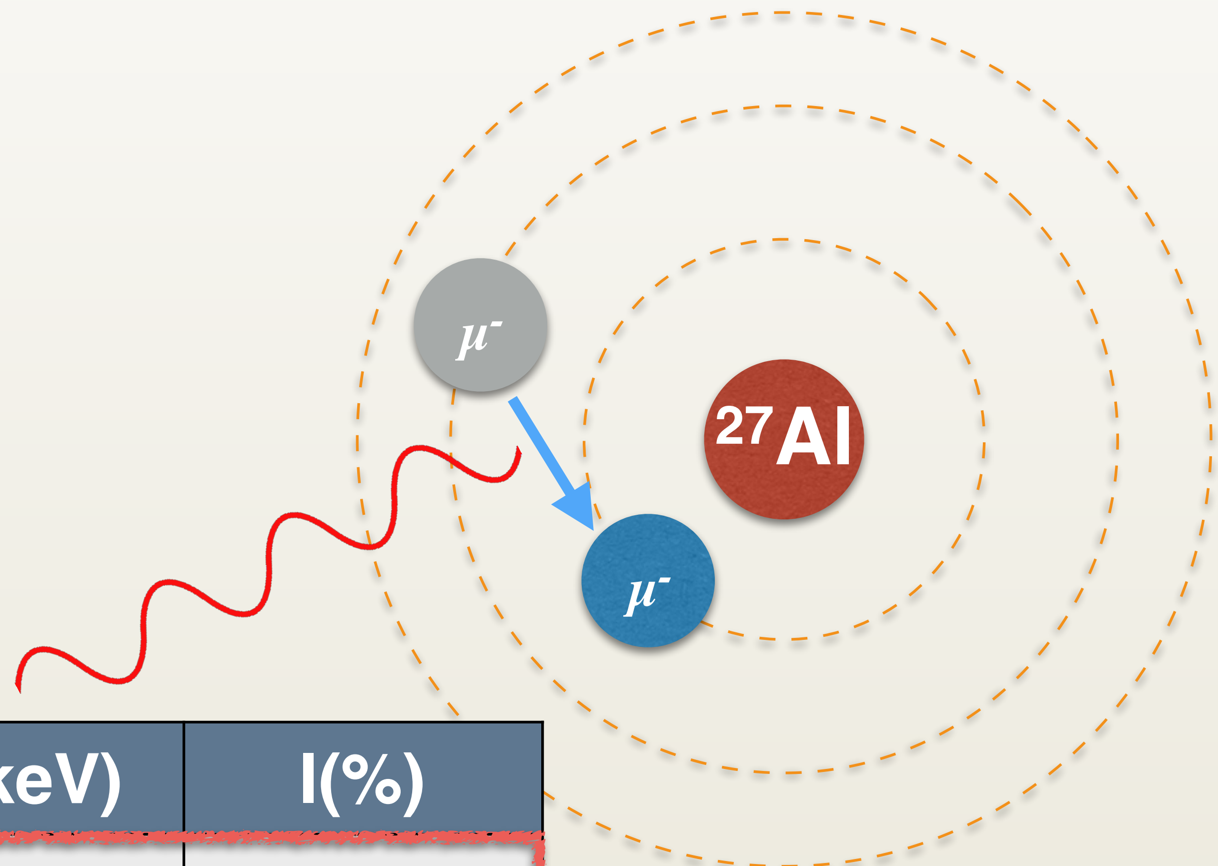
Conceptual design

- Measuring observable(s) directly associated with a stopped muon
  - characteristic muonic X-rays
  - prompt gamma rays
  - decay-in-orbit electrons
- Obvious issues due to Mu2e beam characteristics:
  - very high rate
  - radiation damage

Xrays and gammas



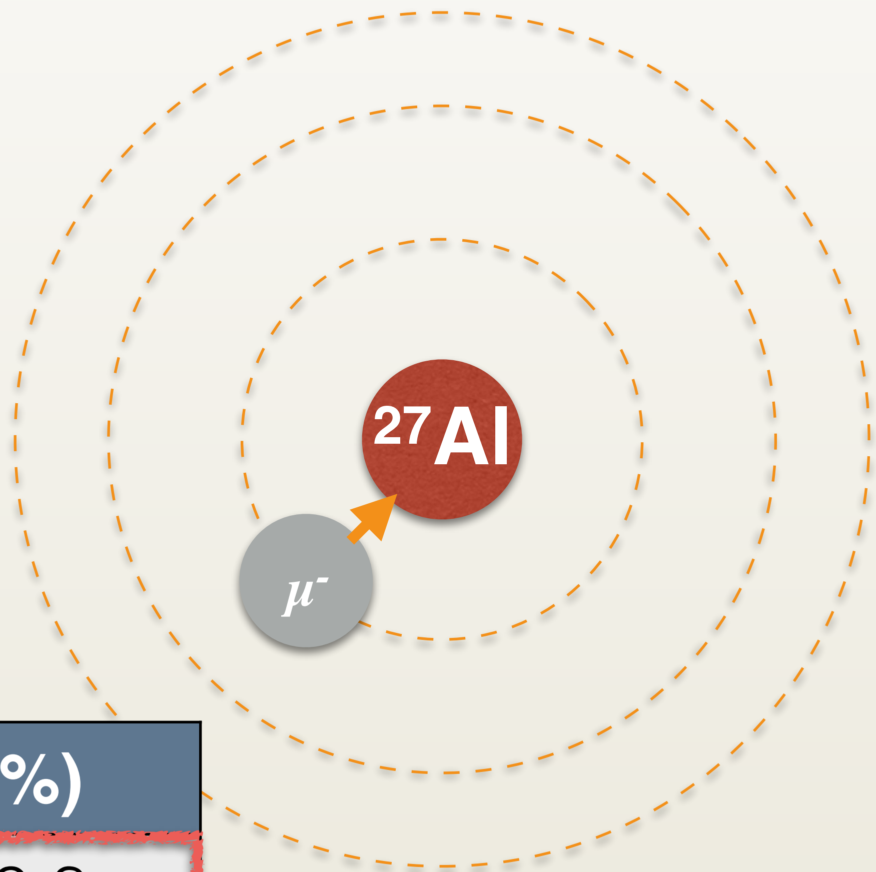
Xrays and gammas



Transition	E (keV)	I(%)
2p → 1s	346.83	79.8
3d → 2p	66.11	67.6
3p → 1s	412.87	7.6
4p → 1s	435.96	4.9

Muonic X-ray from Al prompt with atomic capture

Xrays and gammas



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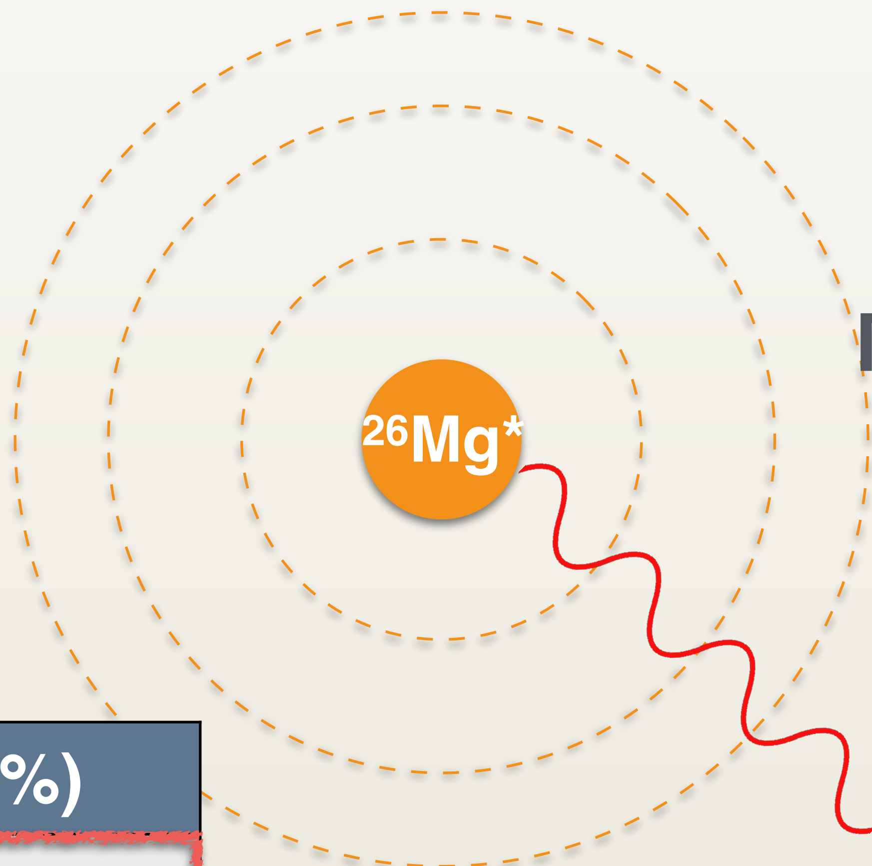

Main gamma of interest, prompt with nuclear capture

Energy	1808.7 keV
Lifetime	476 fs
Intensity	51%

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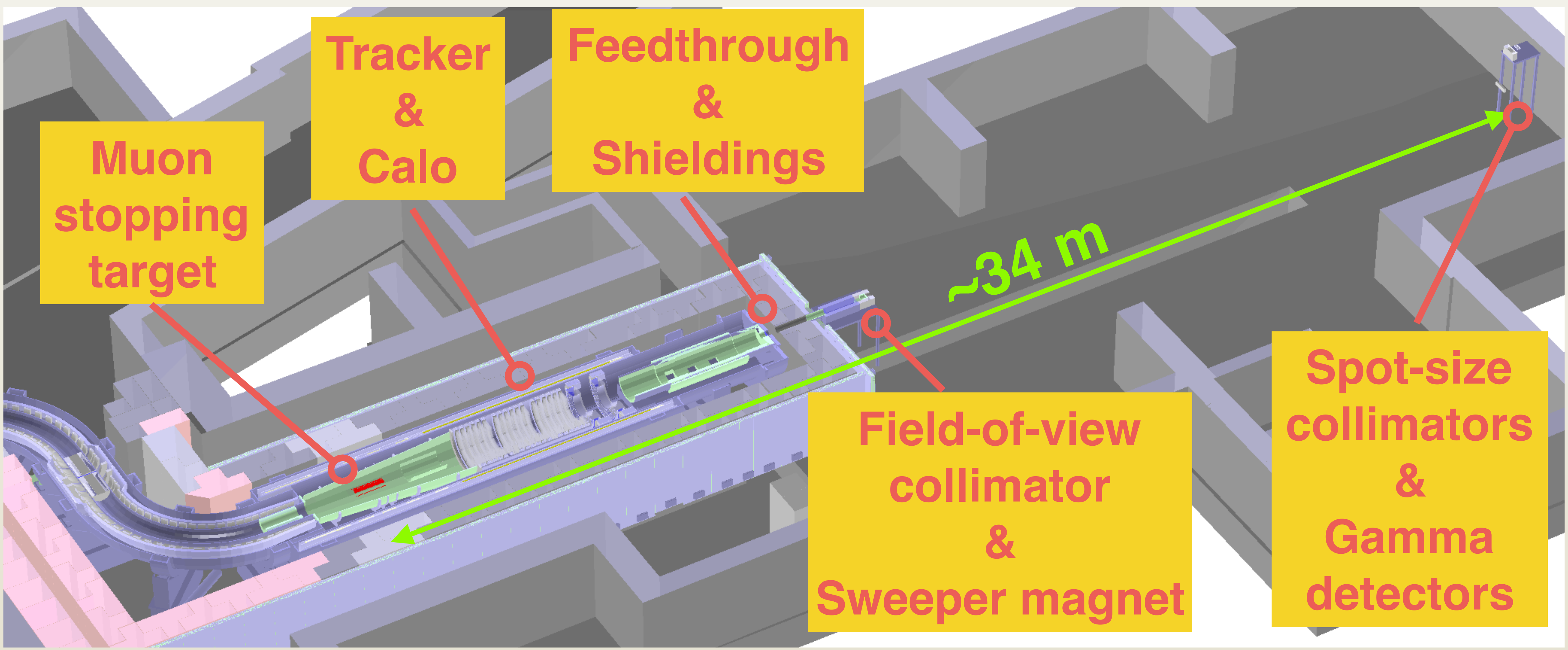
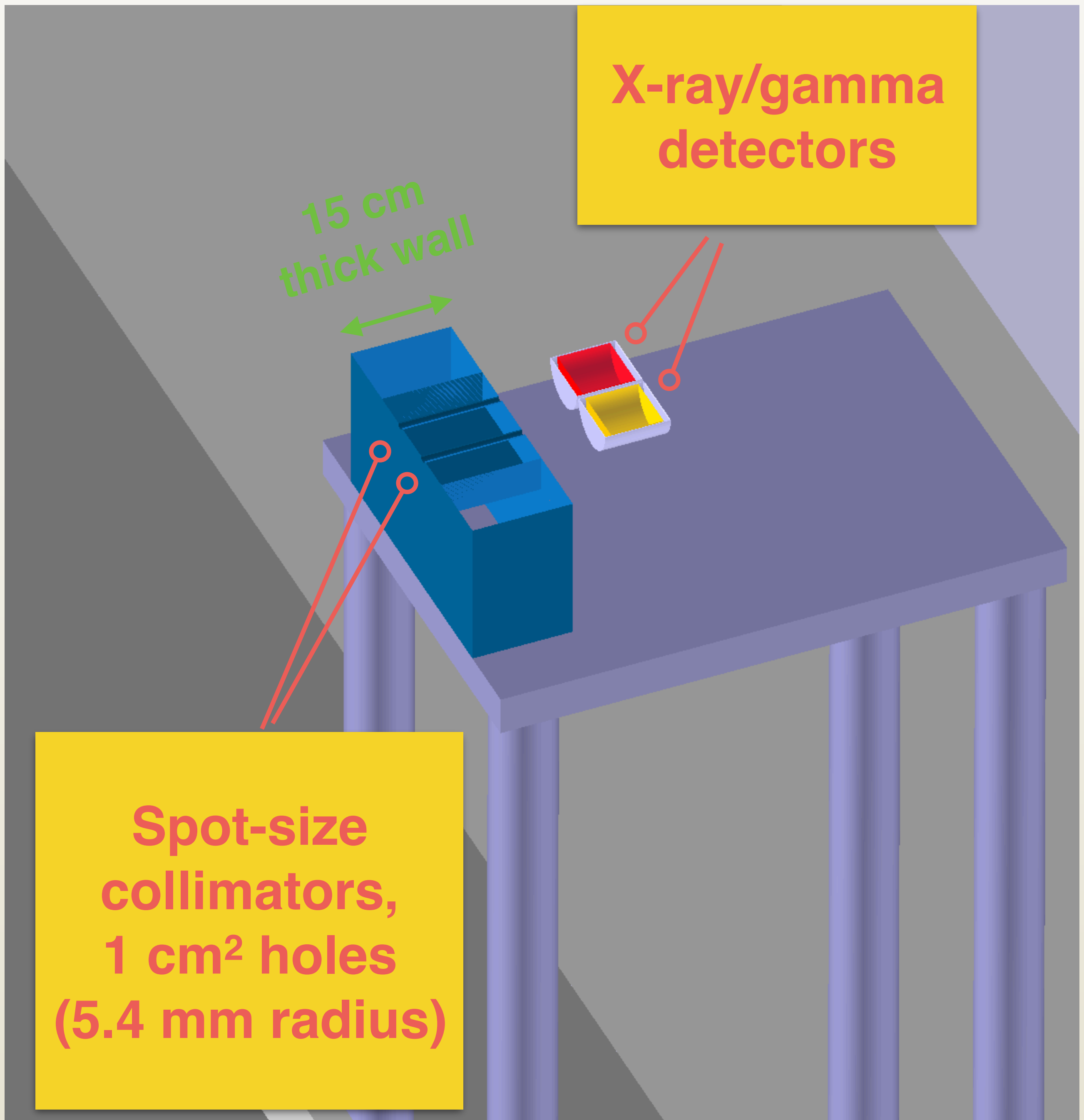
Muonic X-ray from Al prompt with atomic capture

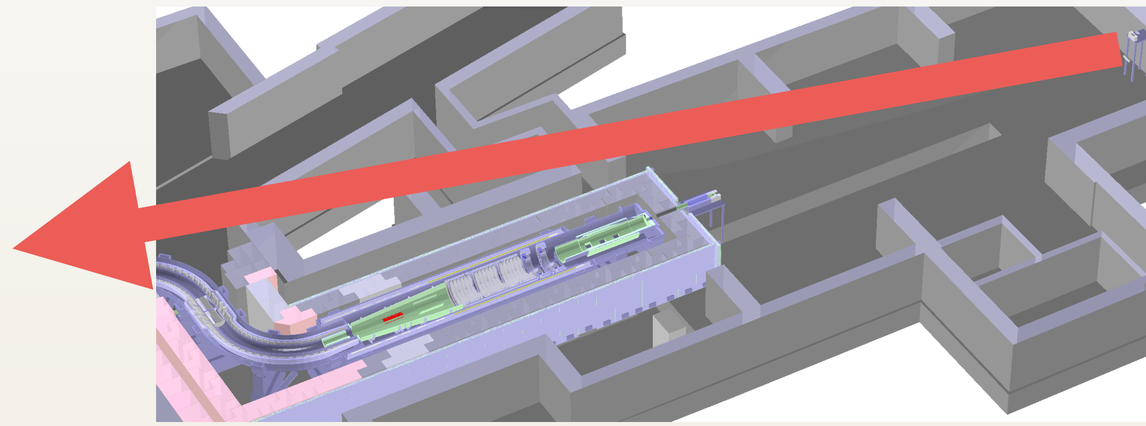
Conceptual design

- Collimators to define the view of the stopping target
- Minimize that rate



Detector candidates

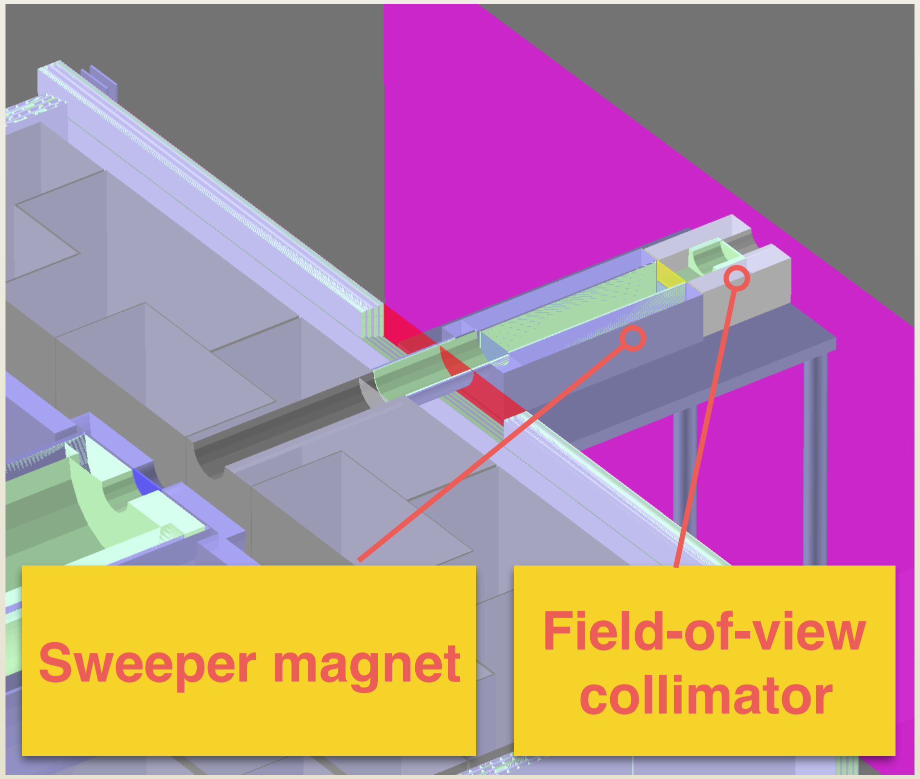


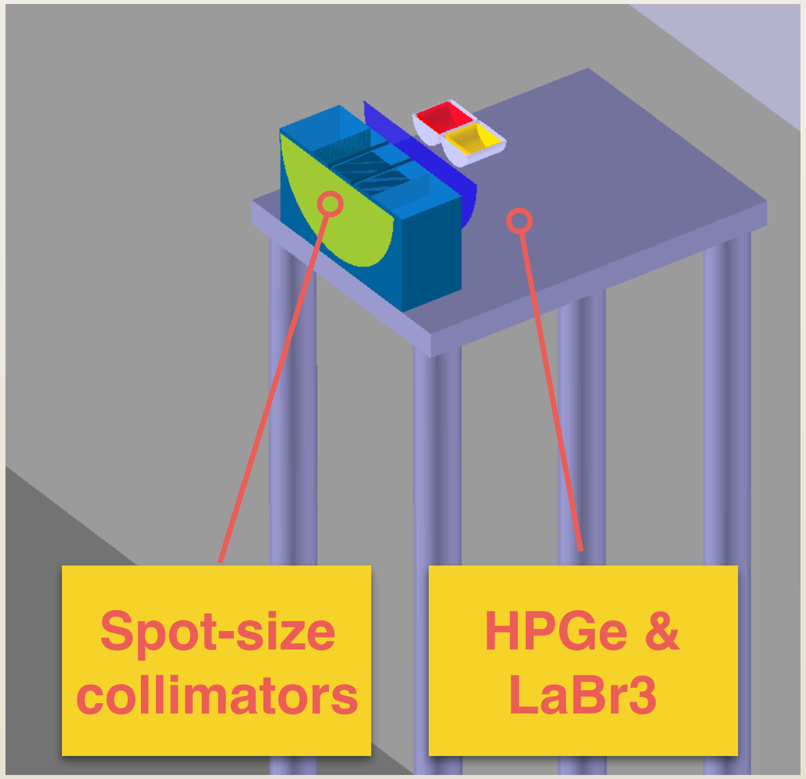


- High-purity Ge (HPGe):
  - excellent energy resolution (< 2 keV)
  - slow
  - susceptible to radiation damage
- LaBr3:
  - worse energy resolution
  - very fast
  - radiation hard

Simulation

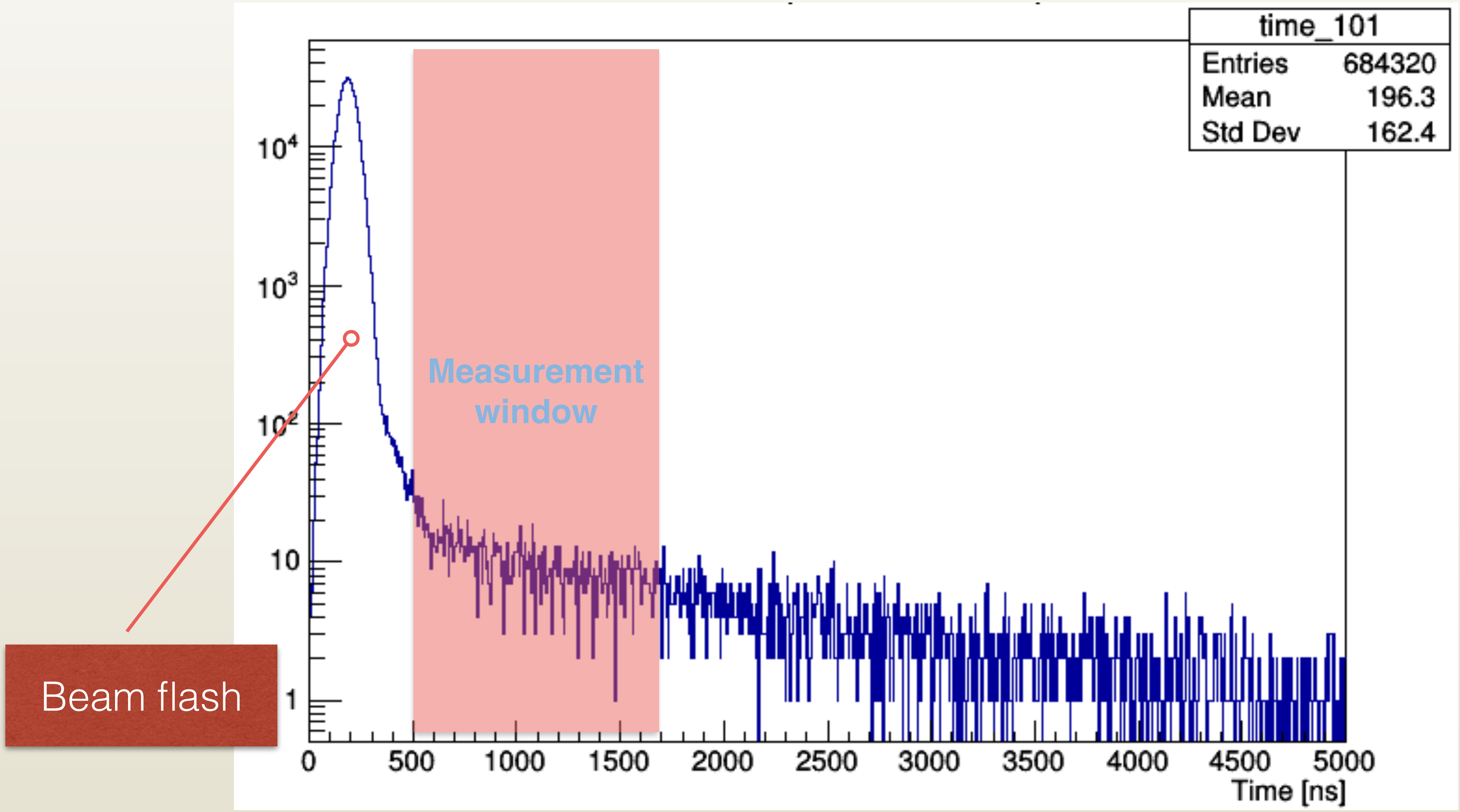
- Mu2e's Geant4-based software with full geometry
- 8×10^{11} protons on target simulated in total
- Observed particles at several virtual detector planes downstream of the muon stopping target





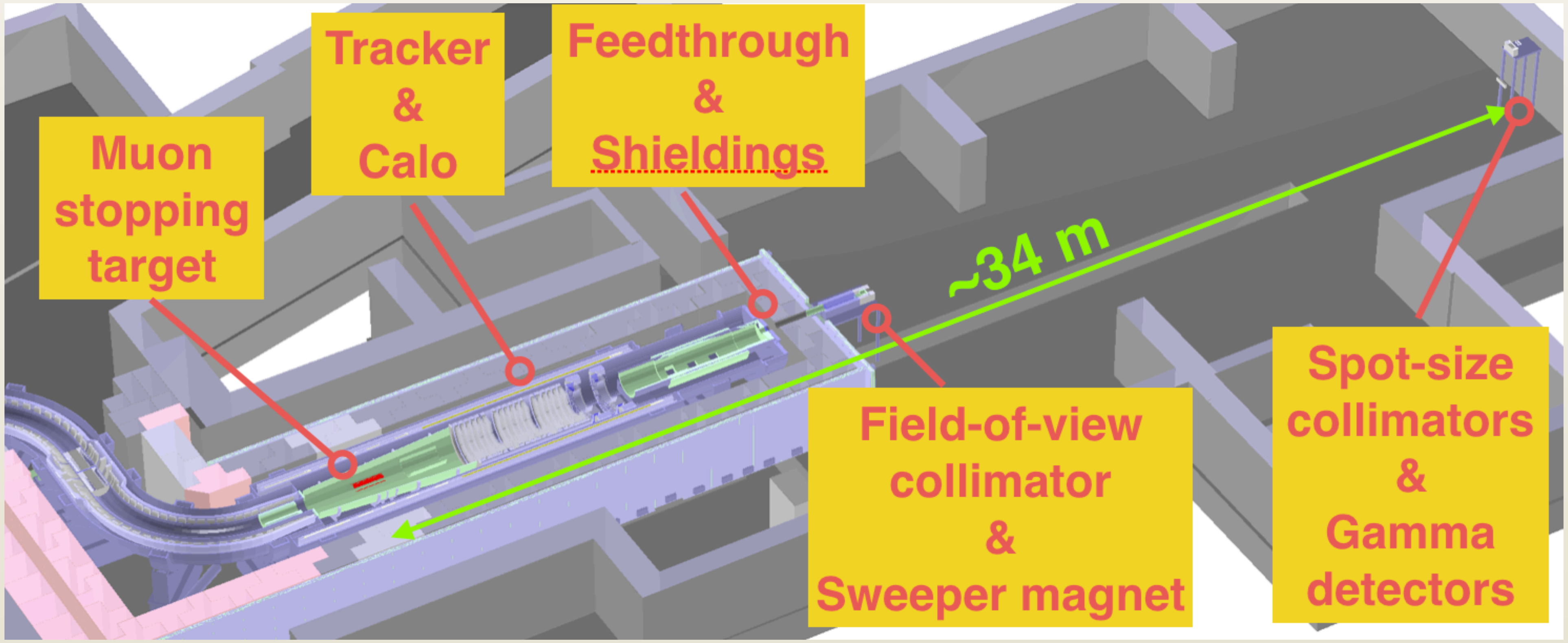
Measurement window

- Timing of hits just upstream of the detectors



Particle types

Location	Photon(%)	Electron(%)
Upstream of the sweeper magnet	56.06	43.67
Upstream of the detectors	98.31	0.74

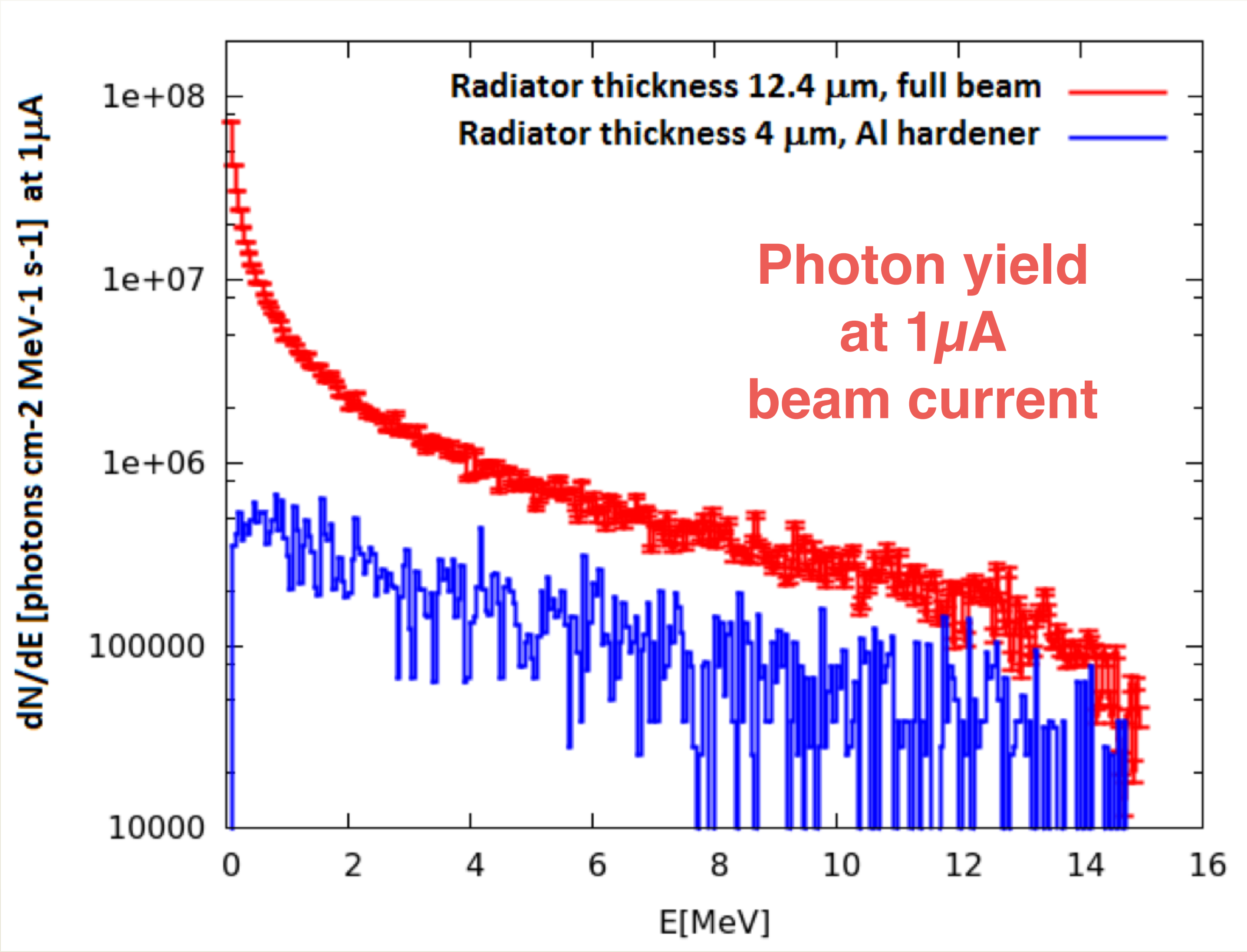


Hit rate estimation

- 160 kHz instantaneous rate on the HPGe/LaBr3 detectors
  - nominal 3.1×10^7 protons per pulse
  - 1.7 μs interval between pulses
- Commercial HPGe's performance falls off around 10 kHz
  - Purdue group achieved 2 keV resolution, 3.2% event loss at 150 kHz
  - Also have experience with annealing
- An absorber is still needed upstream of these detectors

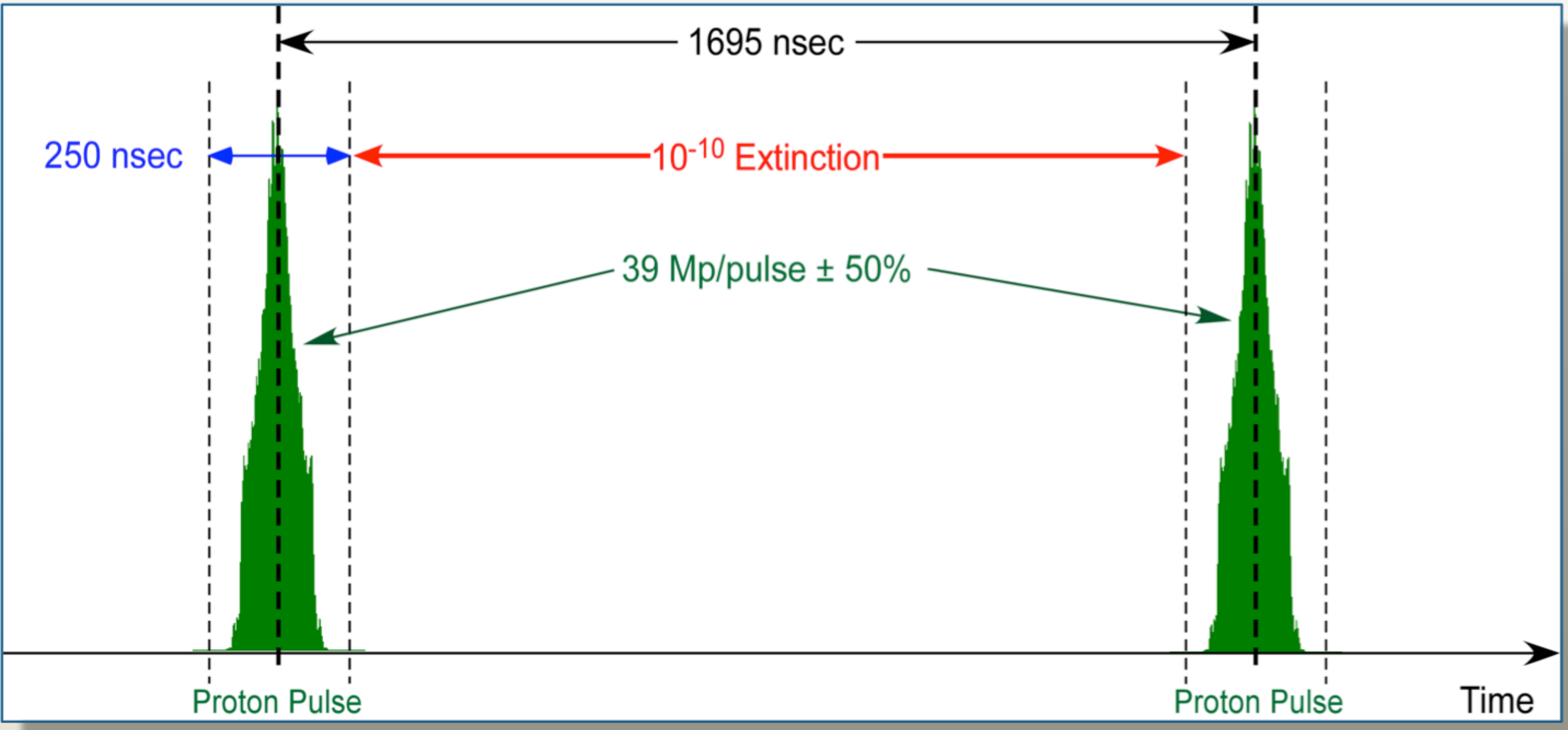
Performance test of Ge detectors

- A beamtest at ELBE (Dresden) is scheduled in early August
  - High flux pulsed gamma beam
    - driven by a continuous-wave electron beam
    - mimic the expected rate ~160 kHz
  - Detector performance after a flash



Summary

- Counting number of stopped muons is important for Mu2e
- Baseline design: use a HPGe detector to measure prompt X-rays and gammas.
    - need to solve problem of high rate and radiation damage
- Simulation work and beam test are ongoing to finalize the design.


1695 nsec
250 nsec
10^{-10} Extinction
39 Mp/pulse ± 50%
Proton Pulse
Proton Pulse
Time

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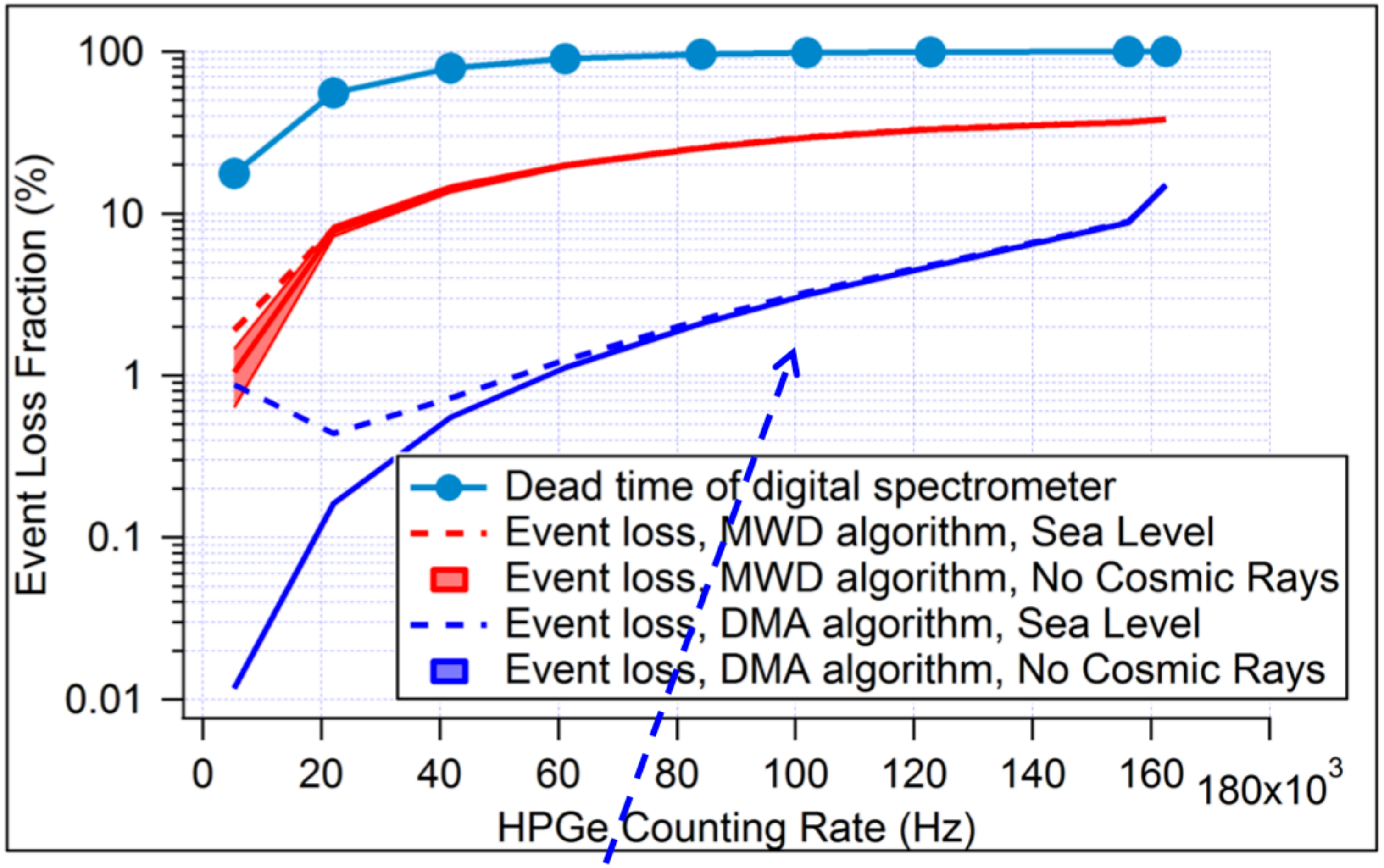
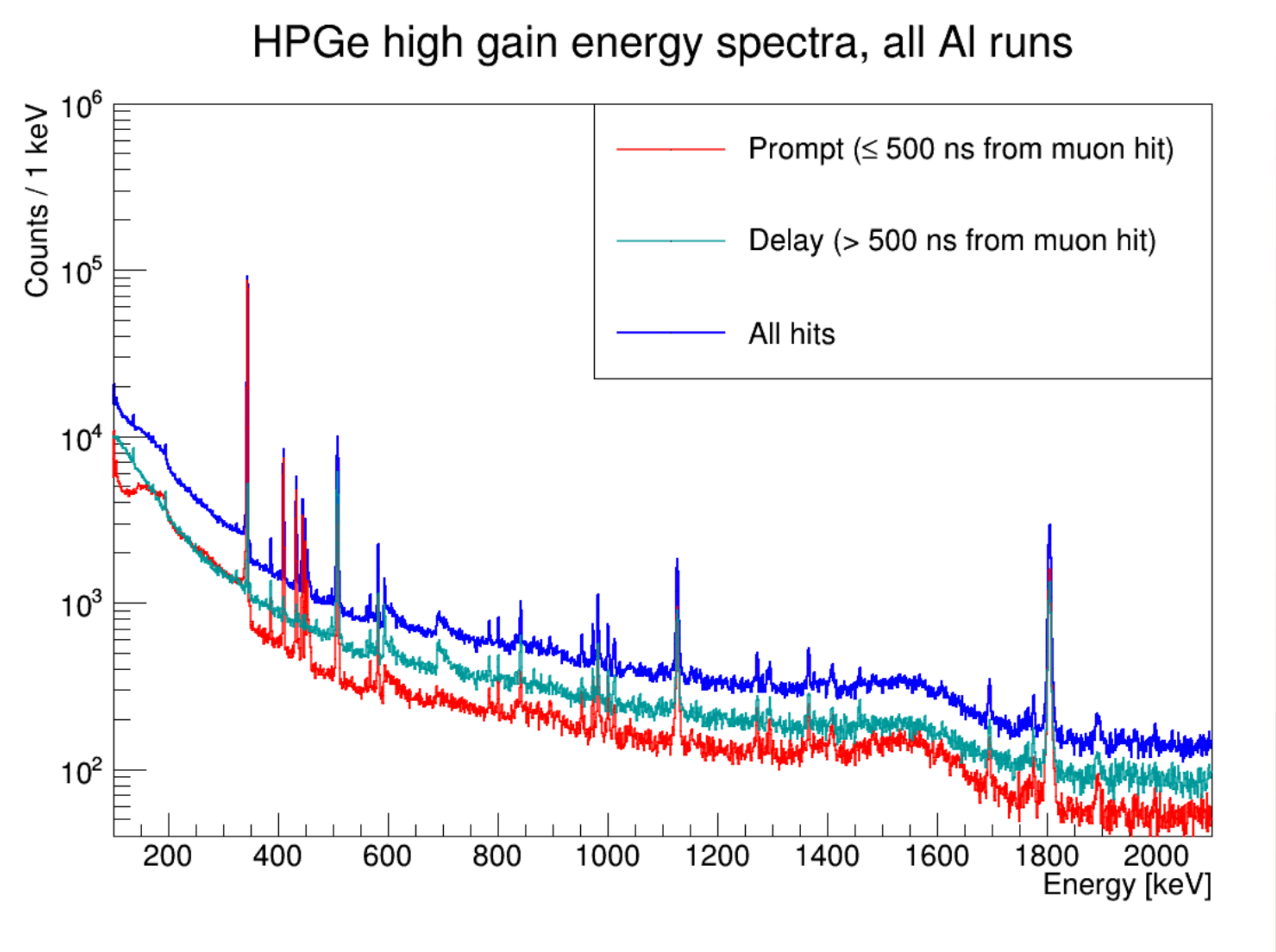
4. Deadtime and Event Loss Issue at Continuous Mode

$$Event\ Loss\ Fraction = 1 - \frac{Registered\ Events}{Pileup\ Events + Detected\ Events\ (-Cosmic\ Events)}$$



For rates ~100 kHz, the DMA algorithm is able to keep:
(1) Dynamic range overflow event loss < 5.8×10^{-3}
(2) Pile-up event loses to < 2.6×10^{-2}
in both ~100% n-type and p-type HPGe detectors.



	347 keV ($\sigma = 0.884$ keV)	844 keV ($\sigma = 0.76$ keV)	1809 keV ($\sigma = 1.8$ keV)
Incident on the det.:			
S/B	$112.9/289.2 = 0.39$	$6.7/113.7 = 0.06$	$56.9/118.7 = 0.48$
S/B (prompt)	$100.1/10.0 = 10.1$	$5.9/3.9 = 1.5$	$50.5/4.1 = 12.3$
S/B (semi-prompt)	$12.3/1.0 = 11.9$	$0.73/0.41 = 1.79$	$6.2/0.43 = 14.5$